FORUM-AE COORDINATION ACTION

FP7 European coordination action ; GA 605506 ; 2013-2017

Emissions Mitigation Concepts

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Olivier Penanhoat, Yoann Mery, Nicolas Tantot (Safran-AE)

ECATS 2nd Conference on Making Aviation Environmentally Sustainable and Climate Change Joint Workshop with FORUM-AE
Athens – 8th Nov. 2016

www.forum-ae.eu
ACARE Environmental Goals by 2050

- CO₂ emissions per passenger kilometre have been reduced by 75%, NOₓ emissions by 90% and perceived noise by 65%, all relative to the year 2000.

- Aircraft movements are emission-free when taxiing.

- Air vehicles are designed and manufactured to be recyclable.

- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.

- Europe is at the forefront of atmospheric research and takes the lead in formulating a prioritised environmental action plan and establishes global environmental standards.
Continuous Effort on Technology to Reduce Fuel Burn and CO2
# World-Leading Product Evolution

![Diagram of Trent XWB, Advance, and UltraFan™/Open Rotor]

## Technology EIS Readiness

<table>
<thead>
<tr>
<th></th>
<th>2020+</th>
<th>2025+</th>
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<tbody>
<tr>
<td>Bypass Ratio</td>
<td>11+</td>
<td>15+</td>
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<tr>
<td>Overall Pressure Ratio</td>
<td>60+</td>
<td>70+</td>
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<tr>
<td>Efficiency relative to Trent 700</td>
<td>20%+</td>
<td>25%+</td>
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</table>
World-Leading Product Evolution

Trent XWB

World’s most efficient engine

Integrates Propulsion System
Lightweight LPT System
Hollow Ti Fan System
3 Stage Turbine Core

Advance

Integrates Propulsion System
Lightweight LPT System
CTi Fan System
Advance Core

UltraFan™ / Open Rotor

Integrates Slim Line Nacelle (No Thrust Reverser)
Geared Multi Stage IPT System
Variable Pitch CTi Fan System
Advance Core
Advance – Technology Advances

- Lightweight CTi Fan System & ENABLES
- Low NOx Combustor
- Advanced Turbine Cooling & Materials
- Lightweight High Efficiency Turbines
- Lightweight High Efficiency Compressors
- Advanced High OPR Cycle
- Dynamic Sealing
- Smart Adaptive Systems
- High Torque Density Shafts
- Hybrid Ceramic Bearings
- Adaptive Cooling System

Key Benefits:
- Fuel Burn
- Environment
- Maintenance
UltraFan – Technology Advances

- Variable Pitch / Variable Area Nozzle
- Fully Integrated Slim-line Nacelle
- Advanced CTi Fan System & ENABLES
- Low Speed Fan System
- Power Gearbox
- Advanced Hybrid Ceramic Bearings
- Cooled Cooling Air
- Multi Stage IP Turbine System
- High Aspect Ratio TiAI / CMC IP Turbine Aerofoils
- Advanced Cooling and Broader Application of CMCs
- Next Gen High Strength Ni Alloy
- Blisk & MMC Bling Compressors

Key Benefits:
- Fuel Burn
- Environment
- Maintenance

6 / ECATS/FORUM-AE Joint Climate Change Workshop (Athens Nov 2016)
MITIGATION SOLUTIONS (SAFRAN-AE)

Continuous Effort on Technology to Reduce Fuel Burn and CO2

(*) Fuel Burn

<table>
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<tr>
<th>Year</th>
<th>Aircraft</th>
<th>Fuel Burn</th>
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<tr>
<td>1970</td>
<td>B727</td>
<td>24%</td>
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<tr>
<td>1980</td>
<td>B737-300</td>
<td>6%</td>
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<tr>
<td>1990</td>
<td>B737-800</td>
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<tr>
<td>2000</td>
<td>A320 1st generation</td>
<td>6%</td>
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<tr>
<td>2016</td>
<td>A320 2nd generation</td>
<td>15%</td>
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<tr>
<td>2020</td>
<td>A320neo</td>
<td>&gt;10%</td>
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<td></td>
<td>LEAP-X</td>
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</table>

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Exemple: CROR solution

- A Counter Rotating Open Rotor (CROR) is expected to provide a significant benefit in terms of FB/CO2 reduction, with an estimated reduction of -35% on a SMR aircraft, compared to 2000 technology.

- The development of this engine requires advanced solutions in terms of aerodynamics, acoustics and mechanics. It requires also a much stronger integration to the aircraft than usual turbofans.

- A demonstrator (pusher type) is developed in CS SAGE2 ITD under Safran-ae lead and should be tested beginning of 2017.
Exemple: CROR solution

- Success of CROR is based on many new technologies: new components (high power counter-rotating gearbox, rotating frames…), adapted mounting system design, specific control system…
- Overview of demonstrator’s bricks and breakdown with partners:
MITIGATION SOLUTIONS (SAFRAN-AE)

Promising but more to be done

ACARE 2020 CO2: -50% (kg/km/pass)

CO2 reduction (%) vs. NOx margin from CAEP6 (%)

Eng. Cycle & Comb. Techno

CROR*

UHBR*

* including ATM improvement assumption
CO2 MITIGATION SOLUTIONS

- **ACARE 2050** very challenging CO2 reduction objective would permit to mitigate substantially the effect of traffic growth.
  - So, it is essential to pursue a tremendous effort at the aircraft level, the engine level and the ATM & flight operation level in order to progress towards this ambitious goal.

- **Unconventional configurations** like aircrafts equipped with CROR concept or UHBPR concepts, must be further developed.
  - Their mitigation potential, complemented with laminar wing benefit, must be maximised and their maturity must be pushed over TRL5
EU R&T Technology Programmes

Whole Engine Demonstration

Low Noise
- Openair Silencer
- SAGE 1

Low CO₂
- NEWAC
- E-BREAK
- LEMCOTEC
- Factor
- ERIKA

Low NOx
- SAGE 6 Lean Burn Combustor

New engine Architectures
- Dream Enoval +
- LEMCOTEC
- FIRST

Rolls-Royce & FP7: 39 projects
Rolls-Royce & Clean Sky: 4 major demonstrators
Continuous effort (on combustor techno) to reduce non-CO2 emissions
Safran-ae lean combustion technology is called MSFI (Multi Staged Fuel Injection).

Optimisation of the fuel split between the pilot injector and the primary injector is supported by LES calculations (stronger interaction between pilot & lean flame is seen at 20% split).
Consensus appears that fine particles (nvPM) reduction must be also achieved, in addition to NOx. This induces critical R&T on:

- **The combustor technology itself in order to reduce both NOx & nvPM**
  - enhanced lean combustion in general (achieving TRL6 maturity & extending its application to smaller size and/or smaller OPR engine combustors),
  - focus on more specific aspects which may be beneficial to particles reduction

Lean combustion technology: Snecma calculation (left), Rolls-Royce solution (right)
Rolls Royce Lean Burn Pre-Production Validation

- E3E Core (operability)
- EFE (Emissions and high T performance)
- ALECSYS (Trent engine) System Commissioning
- Stennis (Noise)
- Manitoba (Icing)
- Flying Test Bed (In-flight Operability)
CO2 MITIGATION SOLUTIONS

- Aircraft/Engine technologies must be further and continuously improved
  - both for evolutionary aircraft/engine applications and longer term disruptive ones

- More radically unconventional solutions (distributed propulsion a/c…) should be also considered for much longer term and at lower TRL

Propulsive-Fuselage Concept (PFC)
Distributed Multiple-Fans Concept (DMFC)

DISPURSAL Project Analysis
## Status against ACARE goals

| Reference 2000 | 
| --- | --- |
| **CO2** | **NOx (LTO)** Representative technology of aircraft & engine with 2000 EIS, & representative 2000 ATM | **NOx (Cruise)** |
| **Other emissions** | **ACARE 2020 Goals** (at TRL6) | **ACARE 2050 Goals** (at TRL6) |
| | **High Level** | **detailed (SRA)** |
| | **High Level** | **detailed (SRIA)** |
| CO2 | "-50% per pass km" | "-75% per pass km" |
| NOx | "-80%" | "-90%" |
| NOx | Achieved through -50% Fuel Burn & -60% cruise EINOx reduction | Achieved through -75% Fuel Burn & further cruise EINOx reduction |
| Other emissions | "damaging emissions reduced" | "emissions qualitatively reduced (particles, CO, UHC) and better understanding of impacts" |
| | | "emissions-free taxiing" + qualitative reduction |
| | | knowledge of emissions (particles, VOC) and better understanding of impacts |

### FORUM-AE Assessment (2015) (extrapol. at TRL6 in 2020)

- **aerospace + engine +ATM:**
  
  - "-38% in average per pass km"
  
- **engine:**
  
  - 
  
  - [-55%, -65%] CAEP6

- **better knowledge of engines particles emissions**
Engine manufacturers spend vast amounts of money on emissions reductions.
Support from States and EU is critical to success of these programmes. Manufacturers match any funding with their own funding.
Airframers expect new engine concepts to be fully tested to high technology readiness level before they will accept them on to new aircraft.
- There are many engine demonstrator programmes for both CO2 and combustion emissions (e.g. NOx reductions) on going and these will define the future aircraft.
- The ACARE targets and Flight Path 2050 targets are extremely challenging but manufacturing industry is fully committed to improving the technology towards those targets.
Evolution of Anthropogenic CO2 from aviation?

**Global aviation CO2 forecast**

- 2050% TO BE UP-DATED WITH COP21 ASSUMPTION
- ~5.5%
- ~2.5%
- ~1.8%
- ~2% 

**Global aviation CO2 forecast assumptions:** ACARE 2050 goal is achieved in 2050 and fully introduced in the 2050 fleet; there is a continuous improvement of average efficiency from now to 2050; ICAO 37th Assembly projected average air traffic growth of 4.6% is taken.
**Very large number of relevant projects**

<table>
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<tr>
<th>PROJECT</th>
<th>T0</th>
<th>STATUS</th>
<th>Coordinator</th>
<th>TITLE</th>
<th>TYPE</th>
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<tr>
<td>REACT4C</td>
<td>2010</td>
<td>Completed</td>
<td>DLR²</td>
<td>Reducing Emissions from Aviation by Changing Trajectories for the Benefit of Climate</td>
<td>Impacts</td>
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<td>ECATS</td>
<td>2005</td>
<td>Foundation</td>
<td>ECATS²</td>
<td>Environmental Compatible Air Transport System</td>
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<td>MOZAIC</td>
<td>1994</td>
<td>On-going</td>
<td>RC Jülich</td>
<td>Measurement of Ozone, Water Vapor, Carbon Monoxide, Nitrogen Oxide by Airbus In-Service Aircraft</td>
<td>Impacts</td>
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<td>IAGOS</td>
<td>2008</td>
<td>On-going</td>
<td>RC Jülich</td>
<td>In service Aircraft for a Global Observing System</td>
<td>Impacts</td>
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<td>IAGOS ERI</td>
<td>2009</td>
<td>On-going</td>
<td>RC Jülich</td>
<td>In service Aircraft for a Global Observing System / European Research Infrastructure</td>
<td>Impacts</td>
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<td>CARIBIC</td>
<td>2004</td>
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<td>MPI Chemie, Mainz</td>
<td>Civil aircraft for the regular investigation of the atmosphere based on an instrument container</td>
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<td>QUANTIFY</td>
<td>2005</td>
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<td>Quantifying the Climate Impact of Global and European Transport Systems</td>
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<td>SMART Fixed Wing Aircraft</td>
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<td>Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level</td>
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<td>RR²&amp;SN²</td>
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<td>validation of Radical Engine Architecture systems</td>
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<td>MTU</td>
<td>NEW Aero engine Core concepts</td>
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## Monitoring activity (continued)

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<td>KAI</td>
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<td>Knowledge for Ignition, Acoustics and Instabilities</td>
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<td>FIRST</td>
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<td>FACTOR</td>
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<td>SN*</td>
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<td>IMPACT-AE</td>
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<td>Design methodologies</td>
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<td>Technology Enhancements for Clean Combustion</td>
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<td>INTELECT D.M.</td>
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<td>TLC</td>
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<td>COREJet-fuel</td>
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<td>Coordinating research and innovation of jet and other sustainable aviation fuel</td>
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<td>Team-Play</td>
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<td>Development of the technical basis for a New Emissions Parameter covering the whole AIRcraft</td>
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MITIGATION SOLUTIONS (SAFRAN-AE)

nvPM mitigation – RQL technology

A) Formation espèces précurseurs
Oxydation du carburant et formation C2H2 & HAP suivant les conditions de réalisation de la combustion & la nature du carburant

B) Nucléation & croissance par collisions
Formations de micro-aérosols et condensation ultérieure d’espèces issues des SOx, NOx, des hydrocarbures imbrulés

Aromatiques! formés par la combustion ou initialement présents dans le carburant

Particules! (nvPM)

ECATS/FORUM-AE Joint Climate Change Workshop (Athens Nov 2016)
World-leading product evolution

Trent XWB

World’s most efficient engine

• Drives a high pressure ratio core via 3 stages of turbines (1 HP, 2 IP)

Advance

• Redistributes workload between the IP and HP compressors and turbines

UltraFan™ / Open Rotor

• An enhanced IP turbine drives the fan via a power gearbox, allowing deletion of the LP turbine
NOx (Engine)

ACARE goal -90% NOx overall reduction:
- -75% Rolls-Royce contribution
- -15% from operational efficiency improvements
Rolls Royce Lean Burn Combustion System Architecture

- Compact nested pilot staged lean burn fuel injector
- Movement tolerant FSN design
- Conventional ignition system
- Mounting in line with large engine practice
- Optimised combustor volume
- High efficiency dump diffuser
- 3rd generation cooling technology for ultra efficient cooling